Note to both reviewers and the editor

To increase the utility of the data (and given the time that has elapsed since submission), we will update the time series of all products with the years 2024 and 2025. Note that for this temporal extension, the ESA CCI PASSIVE near real time equivalent product from the Copernicus Climate Change Service (C3S) will be used (Dorigo et al., 2025), which is based on the same (passive) input data and v09.1 algorithm as the product currently considered in the manuscript. The corresponding product description will be adjusted.

Reference

Dorigo, W., Preimesberger, W., Lems, J., Frederikse, T., Dostalova, A.: Soil moisture gridded data from 1978 to present, v202505. Copernicus Climate Change Service (C3S) Climate Data Store (CDS), (Accessed on 2025-12-01), url: https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-soil-moisture?tab=overview, 10.24381/cds.d7782f18, 2025.

Replies to RC1: Heye Bogena, 16 Dec 2025

This paper presents 15 years of curated in situ soil moisture time series from the SwissSMEX network and demonstrates how data from 12 grassland stations, providing volumetric soil water content at multiple depths and integrated values down to 50 cm, can be used to analyze drying trends in soil water content. The data set is of broad interest given the increasing occurrence of drought in many regions worldwide under global climate change and fits well within the scope of ESSD. The presented data product will be valuable to the scientific community working on global change and water scarcity issues in alpine regions. It would be great to also include the data in the International Soil Moisture Network (Dorigo et al., 2021).

Unfortunately, the manuscript exhibits several substantial shortcomings with respect to its methods, content, overall structure, and clarity of writing, which need to be addressed in detail (see specific comments below). I have suggested improvements to the text in some places. However, the entire text should be revised by a native speaker. When revising the manuscript, authors should bear in mind that ESSD focuses on the data set rather than on the interpretation of the data.

We would like to thank Heye Bogena for his valuable and constructive feedback. Please find in the following our replies to the general and specific comments (in blue).

We agree that the manuscript includes an application of the presented in situ data and related interpretations. This is intended to demonstrate the ‘validity and applicability’ of the data, in line with the recommendation in Section 3.5 of the ESSD editorial by Carlson and Oda (2018) to demonstrate validity through comparison to ‘prior or alternate products’. We will reframe the text to make this validation purpose of the analysis of summer soil moisture changes and the comparison with the alternative ERA5-Land and ESA CCI PASSIVE products clearer. We will consider adding a separate “Application” section to more clearly separate the description of the in situ data from the analysis of the summer soil moisture trends.

General comments:

The Abstract is overly long and not suitable for ESSD. It should be 150–200 words and focus on the dataset rather than scientific interpretation, describing the data type, size, and spatial and temporal coverage, explaining how the data were collected, briefly outlining quality-control procedures, and clearly indicating where the dataset is available (e.g., repository or DOI).

We will shorten the Abstract and focus more on the presented dataset rather than on the interpretation of the changes in summer soil moisture. We will also indicate where the dataset is available for download.

The Introduction section is too long and includes discussion, which is inappropriate for ESSD. It should instead concisely provide context and justify the dataset by highlighting gaps in existing data, clearly state the dataset's purpose, scope, key variables, and coverage, and emphasize its value.

We will also shorten the Introduction, particularly by condensing the more detailed context in the first paragraph (lines 46-59). However, we believe it is important to provide some background information on the uncertainties of reanalysis-based soil moisture, given that it is a widely used data source due to the scarcity (both temporal and spatial) of in situ soil moisture measurements.

The Conclusion section should be shortened and focus on the dataset rather than scientific interpretations, emphasizing its main contributions, unique features or improvements over existing datasets, and briefly noting potential applications.

Similarly to the Abstract, we will shorten the Conclusion section, focusing more on the dataset rather than scientific interpretations of the analysis of the temporal changes in soil moisture. The latter will be presented as demonstration of the utility of the in situ data.

The manuscript does not provide sufficient references and details for the statistical methods used. Even well-known methods such as the Mann-Kendall trend test should be properly cited and the implementation described (e.g., software/library and version). For example: "The Mann-Kendall test (Mann, 1945; Kendall, 1975) detects monotonic changes over time and is robust to non-normally distributed data. Calculations were performed using the Python library pyMannKendall (vX.Y.Z) at $\alpha = 0.05$, with missing values handled according to the library's default options."

More details and references on the methods and code libraries used will be included as appropriate (see below).

A map showing the locations of the measurement stations should be included, along with a table summarizing key soil properties, such as soil type and texture.

A map with the locations of the stations will be included in the manuscript, and Table 1 will be extended with a column "Soil texture". For further information on soil properties, we will explicitly refer to Mittelbach (2011, Appendix B therein).

Specific comments:

L10: “curated time series of in-situ”

“timeseries” will be changed to “time series” throughout the manuscript. “in situ”, however, should not be hyphenated according to the journal guidelines.

L16: “vertically integrated” or “root-zone soil moisture”

Will be changed accordingly.

L16: “the robustness of recent drying trends”

Will be changed accordingly if still applicable.

L44-59: This section reads more like a discussion and is not directly related to the data presented; it should be rewritten in a more concise way.

As mentioned above (general comments), we will condense the more detailed context in this paragraph.

L45: Is the increase in evapotranspiration significant?

Yes, the increase in evapotranspiration is significant. We will add this and the reference to Scherrer et al. (2022).

L53: “soil moisture”

“moisture limitation” will be changed to “soil moisture limitation”.

L117: Please explain the trapezoidal method.

The following explanation will be added: The trapezoidal integration approximates the integral by assuming a linear variation between the measurements at the individual depths and was performed using the R-function trapz from the caTools package (version 1.18.2). Historically, the integration was performed based on the *n* VWC measurements (VWC_i) at the depths z_i of 0.05, 0.10, 0.30 and 0.50 m (Mittelbach and Seneviratne, 2012), plus an additional value of VWC at the surface, which is set equal to the measurement at 0.05 m depth (Eq. 1).

$$IWC_{orig}\ (\text{in mm}) = \left(VWC_{0.05\text{m}} \cdot 0.05\ \text{m} + \sum_{i=1}^{n-1} \frac{VWC_{i+1} + VWC_i}{2} \cdot (z_{i+1} - z_i) \right) \cdot 1000 \qquad (1)$$

DOI references for the R-packages will be added.

L115-143: This section on data processing is very confusing. The processing steps are not clearly presented, and information on data processing, e.g. sensor calibration and data correction, is missing. It needs to be rewritten in a clearer and more concise manner, with the focus on how the data was processed.

We will add information on the original sensor calibration (by referring to Mittelbach et al., 2011, Mittelbach et al., 2012) and on the data quality control of the VWC measurements. To clarify the processing steps, we will further include the formulas for the trapezoidal integration of the VWC measurements to calculate IWC (see above), and for the scaling of the IWC time series (see Replies to RC2 below).

L164: "0–0.5 m (merged)" should be removed, as this information is unnecessary; the acronym IWC is self-explanatory.

"0–0.5 m (merged)" will be removed.

L165: Please clarify how this percentage was determined. Was a statistical analysis performed to derive it, or was it determined in another way?

We consciously selected a fraction of up to 35 % missing days in the calculation of seasonal anomalies, representing a compromise between the resulting availability of stations for the summer drying analysis (see Table 1) and ensuring a reasonable annual data coverage. We will clarify that this 35% threshold has been chosen pragmatically and that it is relevant to the calculation of the yearly summer and summer-half-year values in the text. We will also point out that certain use cases might warrant stricter data availability thresholds.

L184-186: This section should be moved to Chapter 2.1.2. In addition, the weighting function should be presented as a numbered equation. Note that the weights in the equation should not have units of length, otherwise the unit of IWC would be mm·m rather than mm. Combining several measurement depths into a single layer (e.g., 7–28 cm) causes measurements at 5 cm depth to be weighted more heavily. It would be preferable to weigh each measurement depth individually when calculating IWC.

While Chapter 2.1.2 describes the data processing of the SwissSMEX in situ data, this paragraph (L184-186) describes the processing of the ERA5-Land gridded data (Chapter 2.2). As such, the layers are given by the ERA5-Land reanalysis product (which is based on a land surface model) and are not related to the in situ measurements. Since VWC is given in $m^3\ m^{-3}$, its multiplication with the layer depth yields an IWC unit of m (or mm when multiplied by 1000). To more clearly separate these comparison datasets from the presented SwissSMEX data (Chapter 2.1), we will restructure Chapter 2 and present the ERA5-Land and the ESA CCI PASSIVE data under a separate Chapter "2.2 Comparison datasets".

As proposed, the weighting functions will be included as numbered equations.

L186: This is a strong assumption and should be tested using periods for which deeper soil moisture measurements are available.

As mentioned above, this paragraph describes the processing of the ERA5-Land gridded data. The assumption is related to the available layers of the ERA5-Land land surface model and thus cannot be directly tested with deeper soil moisture measurements (which are also less abundantly available). Since we focus on the temporal dynamics of the anomalies, which are dampened in these deeper soil layers, this assumption for the gridded product appears justified.

L188–193: Since these data are not part of the dataset provided with this submission, this section is too excessive and should be reduced to a single sentence.

We will restructure Chapter 2 and present the ERA5-Land and the ESA CCI PASSIVE products under a separate Chapter “2.2 Comparison datasets” to make this distinction from the in situ data clearer. We will also shorten the description of the ESA CCI PASSIVE product so that it is more balanced with the description of the ERA5-Land product.

L199: “in-situ time series”

As mentioned above, “timeseries” will be changed to “time series” throughout the manuscript, while “in situ” should not be hyphenated according to the journal guidelines.

L201: "available on a 0.25° × 0.25° latitude–longitude grid with daily temporal resolution."

Thank you for the suggestion, we will change this text accordingly.

L211: “Figure 3 presents the individual soil moisture anomaly time series of the summer IWC at SwissSMEX stations (2010–2024) for each station combination (Table 1), along with the respective median anomalies.”

Thank you for the suggestion, this will be changed accordingly.

L214–215: The median anomalies appear to exhibit different trends. Please add trend lines to make these differences more clearly visible.

We can add the overall trend lines based on the respective median in Fig. 3 for visualisation. The corresponding description of the Theil-Sen trends based on the various station combinations is given in L234-241, and the numbers are presented in Table 2.

L234: Please explain “Theil-Sen trend”

We will add an explanation of the Theil-Sen trend slope and as well as the Mann-Kendall trend test along these lines: The robust Theil-Sen trend estimator (Theil 1950, Sen 1968) is used to compute trends, while the non-parametric Mann-Kendall trend test is used to determine trend significance (Mann 1945, Kendall 1975). These allow to detect monotonic changes over time and are robust to non-normally distributed data. Statistical significance is indicated by a p-value of less than 0.05. The R-functions sens.slope and mk.test from the trend package (version 1.1.4) are used for the calculation.

L284-285: “ERA5-Land and ESA CCI PASSIVE also show good agreement in the long-term monthly variations of Swiss Plateau soil moisture since 1991…”

This sentence will be shortened accordingly. Note that these are not monthly data, but summer and summer-half-year aggregated values.

L295–299: This summary section does not fit in the Discussion and should be removed.

Thank you for the suggestion. We will integrate the explanation of the Mann-Kendall calculation in the Data and methods section.

L329–330: Domínguez-Niño et al. (2019) found no evidence of decreasing sensitivity of the 10HS sensors in detailed laboratory experiments with different soil materials. However, using only the factory calibration led to much higher measurement errors compared to sensor- and soil-specific calibrations, which could falsely suggest a decrease in sensitivity. This important clarification should be included here.

Thank you for pointing us to this additional evaluation of the 10HS sensors, which we will include in the discussion. Indeed, also the analyses of Mittelbach et al. (2011) and Mittelbach et al. (2012) show that using site-specific calibration of the 10HS sensors (as implemented in the SwissSMEX network) improves their accuracy and increases their measurement range. We will clarify this in the discussion and in the in situ data processing section (Section 2.1.2).

L341-342: “We present a curated and comprehensive set of in situ soil moisture time series from the SwissSMEX stations on the Swiss Plateau.”

This sentence will be changed accordingly.

Figure 1: This figure only shows snapshots of data availability. A time series diagram illustrating the availability of measurements over time would be more informative (see, for example, Fig. 2 in Bogena et al., 2022).

Thank you for this input. We will present the data availability of the TDR and capacitance sensors in two time series diagrams in the revised manuscript (see new Fig. 1 below).

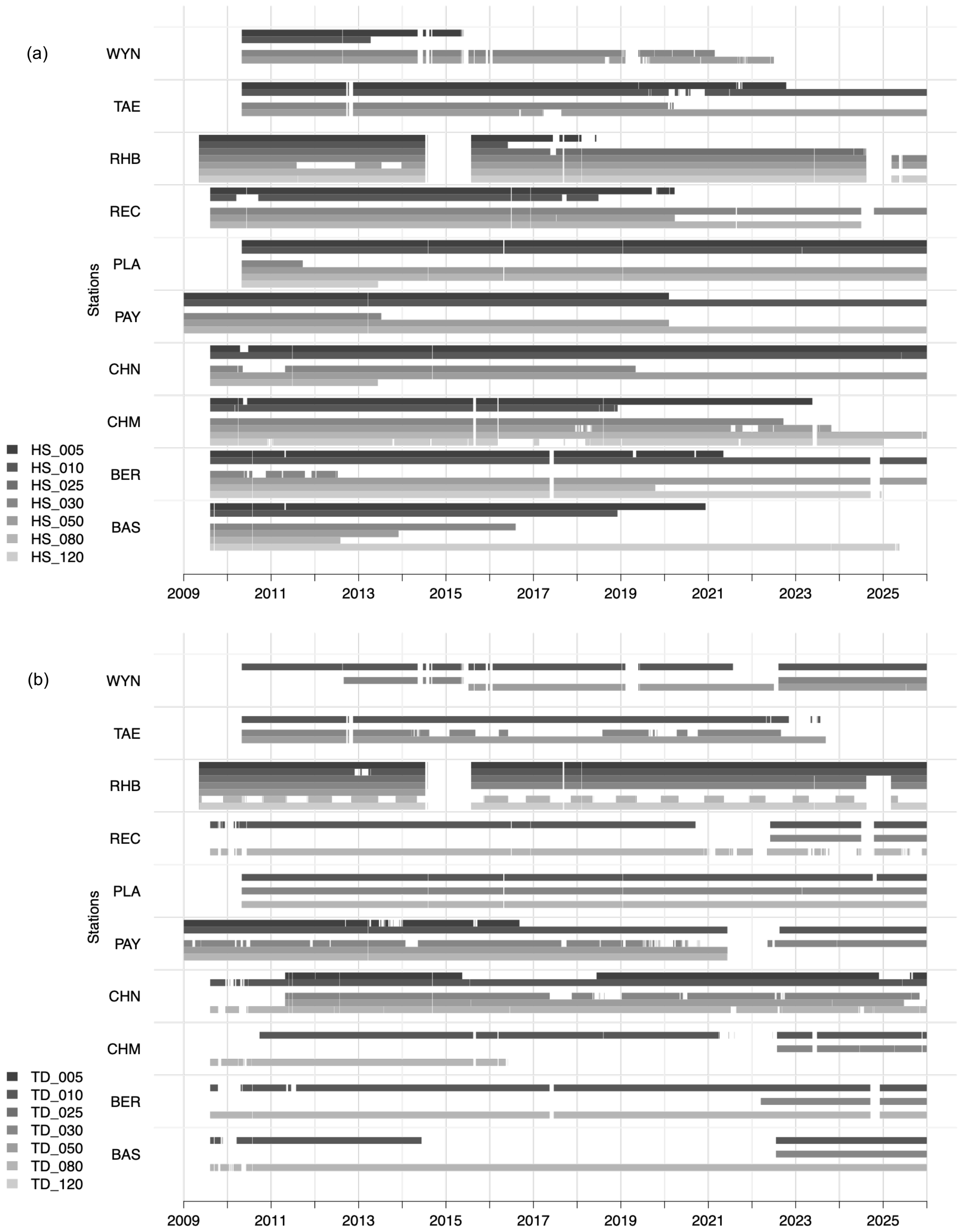

Figure 1 Time series diagram of the sensor availability at the SwissSMEX grassland stations on the Swiss plateau. (a) Decagon 10HS (HS), and (b) IMKO TRIME-PICO TDR (TD) sensors. Abbreviations for station names are given in Table 1, numbers indicate the installation depth in cm. This is a condensed view incorporating all redundant sensor profiles per sensor type. Note that the station RHB includes an additional sensor at 25 cm depth, and that the sensors at the other depths are partly shifted by 5 cm in this profile; for simplicity, the 15 cm sensor is shown as 10 cm sensor, the 35 cm as 30 cm, and the 55 cm as 50 cm for this station.

Figure 2 does not effectively present the data. The many overlaid lines make it difficult to distinguish individual series, and the thick black line is superfluous, as it merely duplicates other datasets. I suggest presenting the data in two additional subplots. In addition, the legend could also be placed outside the plot area so that the data range does not have to be unnecessarily restricted. Finally, similar plots should be provided for the remaining stations in the supplement.

Thank you for the suggestion. In the revised Fig. 2, we will separate the VWC and the IWC curves into two panels (see example of CHM below). Please note that, to ensure comparability, the y-axes are kept consistent between stations. We will also add the corresponding plots for the other stations in the supplement.

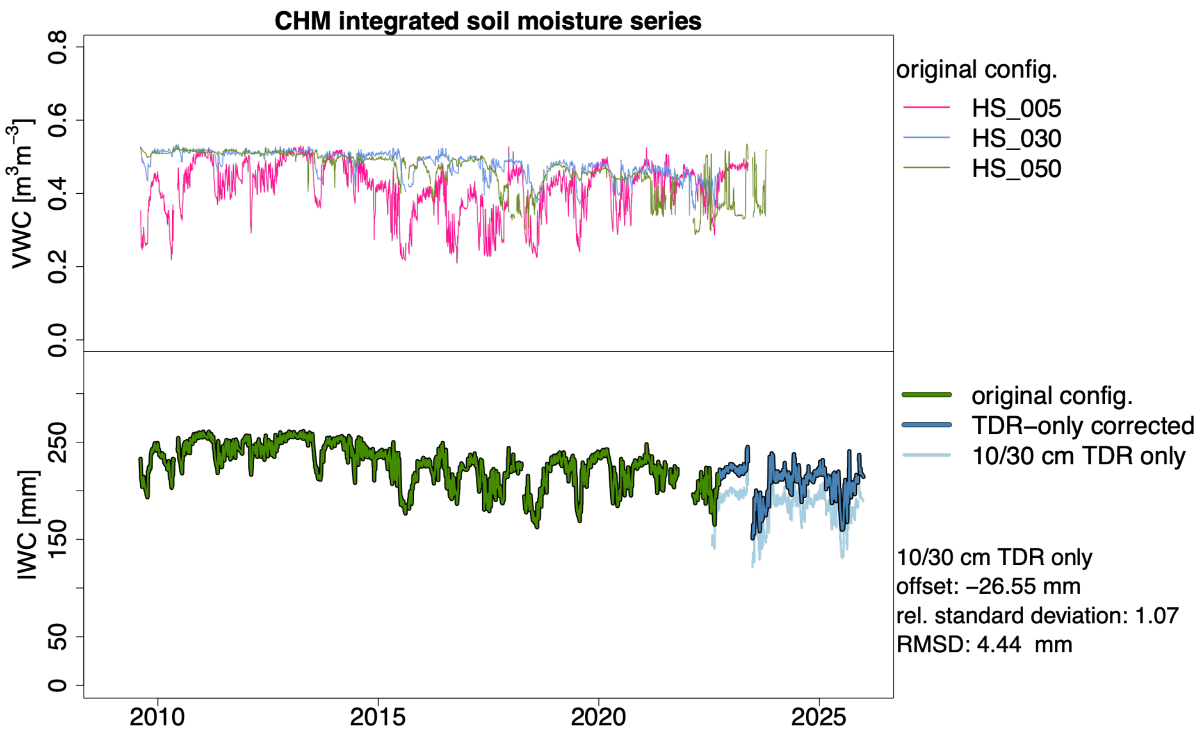

Figure 2 Example illustrating the merging of the historical and TDR-only based 0–0.5 m integrated soil water content (IWC) at the example of Chamau (CHM), where the IWC time series could be extended to near present. (Top panel) Volumetric water content (VWC in m^3 m^{-3}) from the 10HS sensors (see Table S1) contributing to the IWC based on the original sensor configuration. (Bottom panel) Historical IWC (in mm, daily means) based on this original sensor configuration (IWC_{orig}, displayed as thick dark green line), and the 10 and 30 cm TDR-only based IWCs. The thick light and dark blue lines represent the TDR-only time series before ($IWC_{TDRonly}$) and after correction ($IWC_{TDRonly\_corrected}$), respectively (see Eq. 3a,b). The original offset of $IWC_{TDRonly}$ is also noted, as well as its relative standard deviation and RMSD compared with IWC_{orig} (all metrics are based on the overlapping hourly time steps).

Figure 4: The numbers inside the circular areas are not all easily readable and should be made clearer.

We will change the colours of the numbers to make them better readable, with lighter grey for the correlation plot and black/white for the RMSD plot (see Replies to RC2 below).

References

Bogena, H.R., M. Schrön, J. Jakobi, P. Ney, S. Zacharias, M. Andreasen, R. Baatz, … and H. Vereecken (2022): COSMOS-Europe: A European network of Cosmic-Ray Neutron Soil Moisture Sensors. Earth Syst. Sci. Data 14: 1125–1151. DOI: 10.5194/essd-14-1125-2022

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Sen P. K.: Estimates of the regression coefficient based on Kendall's tau, J. Am. Stat. Assoc., 63, 1379–89, 1968.

Theil. H.: A rank-invariant method of linear and polynomial regression analysis, Proc Konink Nederl. Akad. Wetensch. Ser. A Math. Sci., 53, 386–92 (part I), 521-525 (part II), 1397-1412 (part III), 1950.

Replies to RC2: Matthias Zink, 09 Jan 2026

The manuscript and data are fitting to the scope of ESSD. They are about an observational dataset of soil moisture data in Switzerland. The authors present in situ data from volumetric soil moisture that are used to estimate the integrated soil water content. They further validate their data and results of a trend analysis with model data (ERA5 Land) and a remote sensing product (ESA CCI).

The manuscript would benefit from a streamlining of the storyline. Currently the manuscript is divided into a results, discussion and conclusion section. The discussion section includes in major parts results and isn't discussing the results from the results section with exception of a few points. The presented results can be discussed more in depth to support the analyses that have been presented in the results section. Further some figure captions are repeated in the text which elongates the paper unnecessary. The conclusion section is mainly a summary rather than a conclusion section and would benefit from some overhauling.

I also suggest to show some of the maths used for calculating for example IWC and correction/homoginization of the IWC time series.

The manuscript will be well placed in ESSD after some work into streamlining the storyline. It highlights important points like the difficulties of funding and maintaining long-term observational networks and their benefit for climate impact assessment studies. It showcases ideas how to deal with short time series and ways of bringing observations from various instruments together.

We would like to thank Matthias Zink for the positive feedback and the valuable comments. Please find in the following our replies (in blue).

Following the RC1 comments, we will reframe the manuscript to make the validation purpose of the analysis of summer soil moisture changes and the comparison with the alternative ERA5-Land and ESA CCI PASSIVE products clearer. This will include a shortening and streamlining of the whole text.

As proposed, we will include the formulas for the scaling of the IWC time series (see below), and for the trapezoidal integration of the VWC measurements to calculate IWC (see Replies to RC1 above).

Specific Comments:

Can you please add a map of the locations of the stations and add the footprint of the ERA and ESA CCI data.

We will add such a map in a revised version of the manuscript.

L140-144 Can you please elaborate on the scaling one time series with the other using mean and standard deviation. Ideally add the formula.

The scaling is applied to correct the original offset and variability difference of the 10 and 30 cm TDR-only IWC towards the IWC based on the original configuration. This correction assures that the TDR-only IWC data distribution matches that of the original configuration (in terms of mean and standard deviation). This is done as follows:

$$IWC_{TDRonly\_corrected} = \left(IWC_{TDRonly} - \overline{IWC_{TDRonly}}\right) / \, relsd \, + \, \overline{IWC_{orig}} \quad (3a)$$

$$relsd \, = \, \mathrm{sd}\left(IWC_{TDRonly}\right) / \, \mathrm{sd}\left(IWC_{orig}\right) \quad (3b)$$

The overbar denotes the temporal average, sd the standard deviation, and $relsd$ is the ratio of the standard deviations, both calculated based on the overlapping hourly time steps (except for BAS and WYN, where there is no overlap and all time steps are used to calculate the scaling parameters). We will add this in the revised manuscript.

Figure 2: Panel a) is hard to read. It might be useful to move the IWC up to have a better view on the VWC.

Thank you for the suggestion. We will separate VWC and IWC into two panels in the revised Fig. 2 (see Replies to RC1 above).

Figure 2: The figure caption is quite hard to understand.

The separation of VWC and IWC into two panels implies a revision and rephrasing of the figure caption.

L186: assumption VWC28-100cm

This sentence will be changed to: "The assumption is that the $VWC_{28\text{-}100cm}$ is representative for the 22 cm between 28 and 50 cm soil depth."

Can you please elaborate on the meaning of Figure 4? What is the take home message of the pairwise correlations?

The meaning and take home message of Fig. 4 is twofold:

1. For SwissSMEX (values within the red rectangle), the original Fig. 4 shows that the median time series of IWC based on the different station combinations all agree on a consistent temporal evolution, given the high pairwise correlations and comparably low RMSDs. Thus the median evolution of IWC on the Swiss Plateau is mostly independent of the set of stations used. This is presented on L230-232 and will be extended regarding its meaning.
2. For ERA5-Land and ESA CCI, the figure shows the agreement of these gridded products with the in situ data (and among each other). This is again shown for the different station combinations for completeness. These pairwise comparisons show that the independent gridded products agree well with the in situ data for the set of best coverage stations. For the other station combinations, the agreements in the medians is also mostly good. This is presented on L251-263. Note that the agreement of the ESA CCI time series based on the S22 set of stations improved when considering the extended period up to 2025.

To improve the readability of Fig.4 (see below), we will rearrange the pairs of product/station combinations by moving "ERA5-Land bestcoverage", "ESA CCI bestcoverage" and

"SwissSMEX bestcoverage" next to each other. This will make it easier to guide the reader through the different comparisons and ensure that the statistics for the best coverage-based pairs of products are not distributed throughout the matrix anymore.

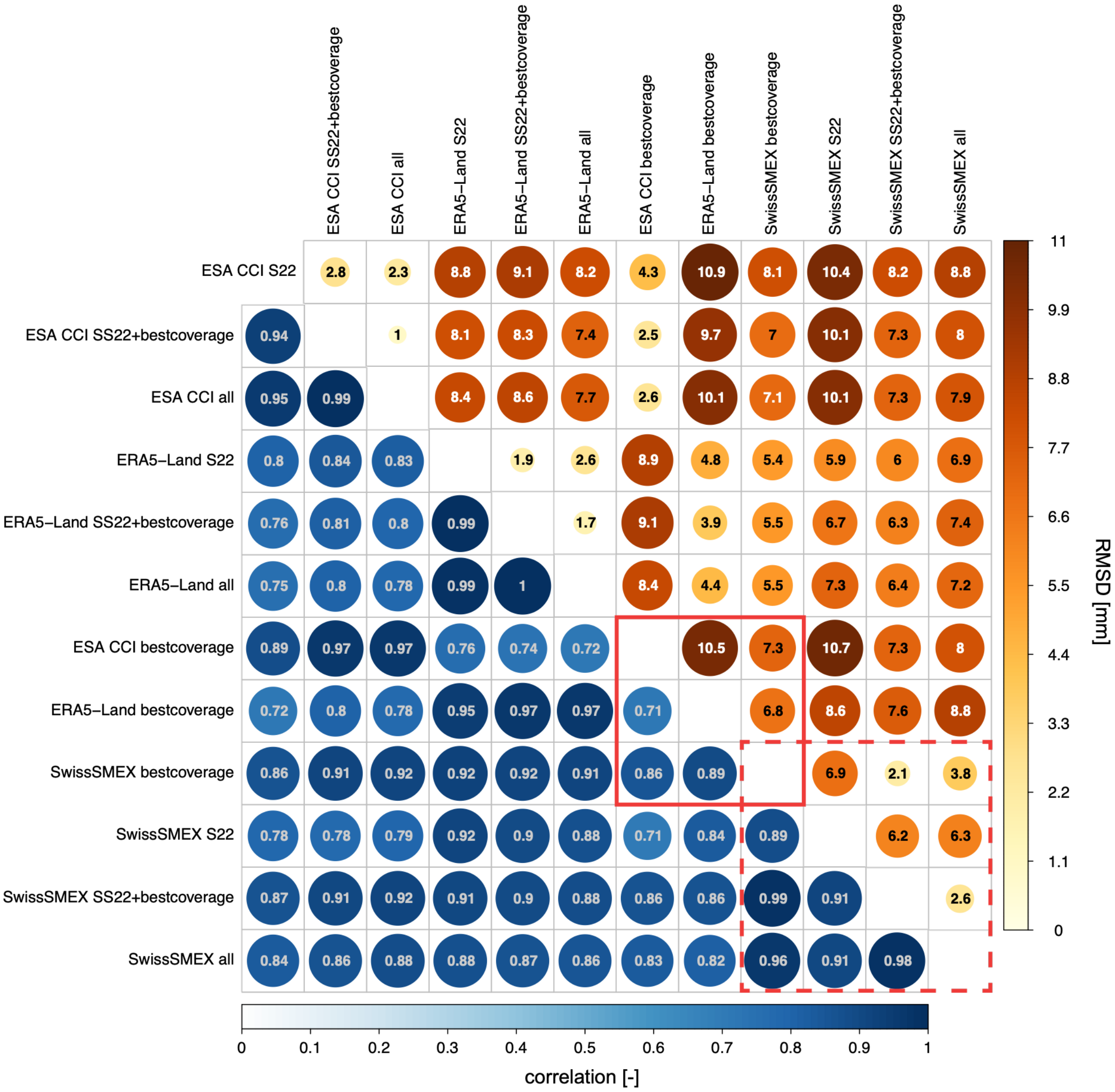

Figure 1 Pearson correlation and RMSD matrices of the pairwise comparison between the SwissSMEX, ERA5-Land and ESA CCI PASSIVE datasets and considering the different station combinations for the Swiss Plateau median time series of summer soil moisture anomalies (expressed as the absolute deviation from the 2010–2020 summer average). Values are calculated based on the common 2010–2025 period. Correlations are all significant (p < 0.05). The red dashed rectangle highlights the comparison of the different station combinations based on SwissSMEX, while the red full-line rectangle highlights the comparison of the gridded products and SwissSMEX based on the best coverage station combination.

L237 for the trends calculated between -0.1 % year-1 and -1.2 % year-1 it would be useful to discuss the accuracy of the measurement devices. This enables the reader to assess the relevancy of the detected trends.

Note that the trends in % year⁻¹ refer to percentage anomalies of the vertically integrated soil water content (IWC), not to volumetric water content (VWC) as directly measured by the sensors. These anomalies are expressed relative to the average summer IWC and thus cannot be directly related to sensor uncertainties. We will clarify this in the revised manuscript.

Figure 5: Can you please increase the font size of the labels and caption? I am not sure if the figure needs to start in 1980. I would suggest zooming in to 2010-2025.

Thank you for the suggestion. As proposed, we will zoom in Fig. 5 to 2010–2025, when we have coverage with the SwissSMEX data (see below). This will also strengthen the validation purpose of this comparative analysis with the ERA5-Land and ESA CCI PASSIVE products. The 1980–2025 evolution will be shown in the Appendix to provide the long-term context. We will also increase the font sizes of this figure.

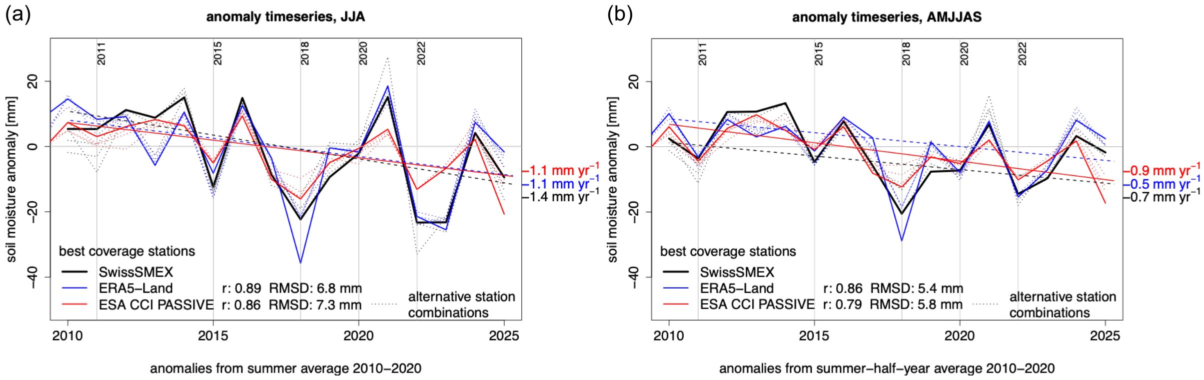

Figure 5 Temporal evolution of (a) summer and (b) summer-half-year soil moisture anomalies based on SwissSMEX, ERA5-Land and ESA CCI PASSIVE. Anomalies are expressed as the absolute deviation from the summer resp. summer-half-year average of 0–0.5 m IWC of the 2010–2020 period (see Fig. S2 for corresponding anomalies as percentage deviations from this average). Shown are the median timeseries based on the best coverage stations (full lines), as well as the ones based on the alternative station combinations presented in Section 3.1 (dotted lines). For the gridded products, the nearest grid cells from the stations are considered as basis for the median. The straight lines show the Theil-Sen trend slopes for the 2010–2025 period (based on the best coverage stations timeseries), which are also indicated to the right of the plots (full lines indicate a significant trend with $p < 0.05$; dashed lines indicate no signifcant trend). Also given are the Pearson correlation r and RMSD of the gridded products with respect to SwissSMEX, and known drought summers are indicated.

Data:

Thanks for including metadata like the soil texture and land cover into the data repository. This is very helpful.

Can you please provide the SiteInfo_SwissSMEX.pdf as ASCII file. This makes it machine readable and hence easier to work with.

We will add the corresponding information as an ASCII text file.

It would be useful to get a lookup table for the nomenclature in the header columns. I know; it can be worked out from the file headers. I would appreciate a dedicated lookup table though.

Thank you for the suggestion. We will include a lookup table as proposed here:

Column	Station full name	Station abbreviation	Sensor type	Measurement depth (cm)
BAS_HS_005	Basel	BAS	10HS	5
...				
BER_TD_010	Bern	BER	TDR	10
...				
WYN_TD_050	Wynau	WYN	TDR	50